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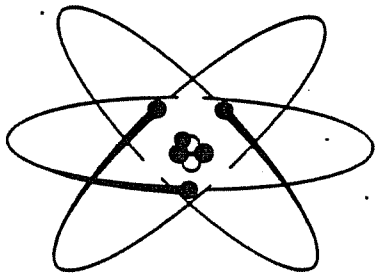
RADIOLOGICAL HEALTH HANDBOOK

Compiled and edited
by the
Bureau of Radiological Health
and the
Training Institute
Environmental Control Administration



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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Rockville, Maryland 20852

Uranium Series (4n + 2)*

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
$^{238}_{92}U$	Uranium I	4.51×10^{9}y	4.15 (25%) 4.20 (75%)	---	---
$^{234}_{90}Th$	Uranium X_1	24.1d	---	0.103 (21%) 0.193 (79%)	0.063c‡ (3.5%) 0.093c (4%)
$^{234}_{91}Pa^{m}$	Uranium X_2	1.17m	---	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
99.87% | 0.13%					
$^{234}_{91}Pa$	Uranium Z	6.75h	---	0.53 (66%) 1.13 (13%)	0.100 (50%) 0.70 (24%) 0.90 (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{5}y	4.72 (28%) 4.77 (72%)	---	0.053 (0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4}y	4.62 (24%) 4.68 (76%)	---	0.068 (0.6%) 0.142 (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 (6%) 4.78 (95%)	---	0.186 (4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49 (100%)	---	0.510 (0.07%)
$^{218}_{84}Po$	Radium A	3.05m	6.00 (~100%)	0.33 (~0.019%)	---
99.98% | 0.02%					
$^{214}_{82}Pb$	Radium B	26.8m	---	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 (6%) 6.70 (94%)	? (~0.1%)	---
$^{214}_{83}Bi$	Radium C	19.7m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
99.98% | 0.02%					
$^{214}_{84}Po$	Radium C'	164μs	7.69 (100%)	---	0.799 (0.014%)
$^{210}_{81}Tl$	Radium C"	1.3m	---	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72 (.000002%)	0.016 (85%) 0.061 (15%)	0.047 (4%)
$^{210}_{83}Bi$	Radium E	5.01d	4.65 (.00007%) 4.69 (.00005%)	1.161 (~100%)	---
~100% | .00013%					
$^{210}_{84}Po$	Radium F	138.4d	5.305 (100%)	---	0.803 (0.0011%)
$^{206}_{81}Tl$	Radium E"	4.19m	---	1.571 (100%)	---
$^{206}_{82}Pb$	Radium G	Stable	---	---	---

*This expression describes the mass number of any member in this series, where n is an integer.
Example: $^{206}_{82}Pb$ (4n + 2).....4(51) + 2 = 206

†Intensities refer to percentage of disintegrations of the nuclide itself, not to original parent of series.

‡Complex energy peak which would be incompletely resolved by instruments of moderately low resolving power such as scintillators.

Data taken from: Table of Isotopes and USNRDL-TR-802.

Commercial Lead Sheets

Thickness		Approximate Weight
mm	in.	lb/ft^2
0.79	1/32	2
1.00	5/128	2 1/2
1.19	3/64	3
1.58	1/16	4
1.98	5/64	5
2.38	3/32	6
3.17	1/8	8
4.76	3/16	12
6.35	1/4	16
8.50	1/3	20
10.1	2/5	24
12.7	1/2	30
16.9	2/3	40
25.4	1	60

Source: Medical X-Ray Protection up to Three Million Volts (NBS Handbook No. 76 [Washington, D.C.: Supt. of Docs., U.S. Government Printing Office, Feb. 1961]), p. 30.

Thickness of Lead Required to Reduce Useful Beam to 5 Percent[a]

Beam Quality		Required Lead Thickness (mm)
Potential	Half Value Layer (mm)	
60 kVp	1.2 Al	0.10
100 kVp	1.0 Al	0.16
100 kVp	2.0 Al	0.25
100 kVp	3.0 Al	0.35
140 kVp	0.5 Cu	0.7
200 kVp	1.0 Cu	1.0
250 kVp	3.0 Cu	1.7
400 kVp	4.0 Cu	2.3
1000 kVp	3.2 Pb	20.5
2000 kVp	6.0 Pb	43.0
2000 kVcp	14.5 Pb	63.0
3000 kVcp	16.2 Pb	70.0
6000 kV	17.0 Pb	74.0
8000 kV	15.5 Pb	67.0
Cobalt 60	10.4 Pb	47.0

[a] Approximate values for broad beams. Transmission data for brass, steel and other material for potentials up to 2000 kVp may be found in reference [15]. Measurements on 1000 kVp and 2000 kVp made with resonant-type therapy units. Data for 6000 kV taken from reference [16], for a linear accelerator. Data for 2000 kVcp, 3000 kVcp, and 8000 kV derived by interpolation from graph presented in reference [17]. The third column refers to lead or to the required equivalent lead thickness of lead-containing materials (e.g. lead rubber, lead glass, etc.).

Source: Medical X-Ray and Gamma-Ray Protection for Energies up to 10 MeV (NCRP Report No. 33 [Washington, D.C.: National Council on Radiation Protection and Measurements, Feb. 1968]), p. 45.

CONCRETE* EQUIVALENTS (mm) OF LEAD AT DIFFERENT X-RAY TUBE POTENTIALS

Lead Thickness (mm)	Tube Potential			
	150 kVp	200 kVp	300 kVp	400 kVp
1	80	75	56	47
2	150	140	89	70
3	220	200	117	94
4	280	260	140	112
6	---	---	200	140
8	---	---	240	173
10	---	---	280	210
15	---	---	---	280

*Density 2.35 g/cm^3.

IRON EQUIVALENTS (mm) OF LEAD AT DIFFERENT X-RAY TUBE POTENTIALS

Lead Thickness (mm)	Tube Potential						
	150 kVp	200 kVp	300 kVp	400 kVp	600 kVp	800 kVp	1000 kVp
1	11	12	12	11	10	9	8
2	25	27	20	18	16	14	13
3	37	40	28	23	19	17	16
4	50	55	35	28	23	20	18
6	---	---	48	38	30	26	23
8	---	---	60	45	36	31	28
10	---	---	75	55	42	36	32
15	---	---	---	75	55	48	43
20	---	---	---	---	70	60	55
50	---	---	---	---	---	125	110

Data for tables from NBS Handbook No. 50.